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PRELIMINARY POLLUTANT LIMIT VALUES FOR ALABAMA ARMY AMMUNITION PLANT

DAVID H. ROSENBLATT, Ph.D.
MITCHELL J. SMALL

Prepared for
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, MD 21010
Mr. Robert Breschi, Project Coordinator

by

U S ARMY MEDICAL BIOENGINEERING RESEARCH & DEVELOPMENT LABORATORY
Fort Detrick
Frederick, Maryland 21701

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of calculations by the Preliminary Pollution Limit Value (PPLV) method for 11 known or suspected soil contaminants at the Alabama Army Ammunition Plant, Childersburg, AL. These contaminants remain from World War II production activities. The results can assist Army managers in decisions involved with the disposition of the plant, now considered excess property. Specifically, soil limits are suggested for

20. Abstract (Continued)

release of land to unrestricted use and land use restrictions are suggested for existing levels of soil contaminations.

The pollutants of concern are: 2,4,6-trinitrotoluene; dinitrotoluenes; 2,4,6-trinitrophenylmethylnitramine; lead; 1,3,5-trinitrobenzene; nitrocellulose; 1,3-dinitrobenzene; diphenylamine; aniline; N,N-dimethylaniline; and nitrobenzene. PPLV values are computed for these substances for several possible future land use situations; subsistence agricultural (essentially unrestricted use); residential housing; apartment housing; industrial; and hunting lands. The PPLV values represent situation-specific soil levels, which based on the methodology and best-available data would be generally considered to present no hazard to humans.

The method suggests that vegetable uptake of pollutants could be the pollutant transmission route which causes severest restriction of land use. In terms of known pollutants and known contamination levels, 2,4-dinitrotoluene and lead are the pollutants of main concern; soil levels of these pollutants are in excess of PPLV values for most land use situations.

TABLE OF CONTENTS

FIGURE

TABLES

INTRODUCTION

The US Army controls large parcels of real estate that are no longer used for military purposes and would not be reactivated in time of full-scale war. Ordinarily, these parcels are excessed by the Army and transferred to the General Services Administration for ultimate disposition, such as sale to non-government purchasers.

Several existing installations are inactive ammunition plants. For the most part, they were procured, constructed and operated for World War II activities. They operated with the conventional manufacturing and waste treatment technology of the times. Explosives removal in wastewater was confined, if at all, to recovery of screenable material. Waste solids were burned in open areas. Portions of these plants and surrounding land were contaminated with chemicals involved in explosives production. Following the end of the war, military industrial operations ceased at these installations. Alabama Army Ammunition Plant is such an installation.

Awareness of the adverse consequences of using land with past chemical production history is very acute in 1981. Land to be returned to unrestricted use must not have residual chemical contaminants at levels that might be harmful to its future inhabitants. Procedures for land renovation, including physical removal and replacement of contaminated soil mass, must meet this goal. The potential costs of renovation efforts must be balanced against the expected benefits. The costs would be borne by the general public, while the benefits would be perceived as locally accrued. Less costly alternatives could be considered, such as restricted land use.

A decision as to how far to go in land renovation depends on what contamination exists and what contamination would be allowable for specified or unrestricted land use. Procedures to derive acceptable soil contamination limits relative to potential land use have not been extensively studied. The authors have participated in an early effort to derive an organized approach to such decision making.[1] The result of this effort was the preliminary pollutant limit value method (PPLV), which has been presented in the open literature.[2]

This report documents the application of the PPLV method to the Alabama Army Ammunition Plant situation. It was prepared to assist the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) in making decisions concerning disposal of Alabama Army Ammunition Plant real estate.

REPORT ORGANIZATION AND CAVEATS

The Site Background section describes the situation existing at the Alabama Army Ammunition Plant in terms of past and present use, and known contamination studies. The section on Substances Selected for Study presents the contaminants specifically addressed in this PPLV method application. The section on Overview of the PPLV Method describes the approach for persons unaware of its formulation, equations, and assumptions. The section on Land Use Scenarios and Pathways outlines various scenarios for land use and attendant human exposure pathways. The section on Scenario-Related Data for Subsequent Analyses documents data required for subsequent computations. The section on Scenario Analysis for Land Use Intensity provides estimates of land

use intensity for the selected land use scenarios. Such estimates allow for a detached cost/benefit perspective of the extent of land renovation that would be required with each scenario. The next section documents the single pathway preliminary pollutant limit value (SPPPLV) computations. The section on PPLV Computations discusses the limiting contaminant concentration values derived through use of the PPLV method and their relation to existing land contamination. The last section provides recommendations for PPLVs related to the Alabama Army Ammunition Plant.

The PPLV method incorporates reasonable assumptions of toxicological data and the modes of human exposure into a computational framework whereby acceptable soil contaminant levels can be estimated. Involved mathematical models are avoided, inasmuch as the available data generally do not support a more complex approach. Toxicological data are derived from studies that may vary widely in relevance to humans and in scientific credibility. The analysis requires several types of data that are either averaged, safe-sided, or scenario-specific. Some numerical inputs should find easy acceptance, while others are based on scanty documentation and guesswork. Efforts are continuing to refine such data. Land contamination values so arrived at should not be construed as official recommendations of the Office of the U.S. Army Surgeon General. Rather, they are the end results of a thought process that the decision-maker may wish to modify, and for which he retains ultimate responsibility.

The temptation to endow a PPLV with an absolute and inviolate nature should be avoided. The PPLV is use-scenario oriented; different PPLVs for the same contaminant are computed for different scenarios. Moreover, the tentative nature of the data elements are such that more refined data may cause a drastic change in a PPLV.

SITE BACKGROUND

Alabama Army Ammunition Plant is located in Talladega County, on the banks of the Coosa River, about 4 miles north of Childersburg, 40 miles southeast of Birmingham, AL. The terrain is level to rolling and generally suited to pasture and timber. Elevations range from about 400 to 580 feet above sea level. The present area is 5,168 acres. The plant was operated between April 1942 and August 1945. It was placed on standby basis until 1975, and then declared to be excessed. The land has been largely used for timber and pulpwood.[3]

The average rainfall in nearby Anniston, AL, is 53 inches.[3] The average depth of sedimentary (limestone) bedrock is 40 to 60 feet, penetrated in places by sinkholes. The limestone bedrock is overlain by silty sandy clays of generally low permeability.[4] The water table, draining to the Coosa River, is very shallow (8 to 20 feet). Any wells dug for a water supply would be to the aquifer below bedrock, and would be of such construction as to prevent contamination from soil at upper levels.[4] The surface soil contains only about 1% organic matter.[5] The background soil-lead content in the local area is about 30 mg Pb/kg.[6]

Figure 1 is a map of the plant; it shows and names various areas in which production or waste-disposal activities were located. The numerical

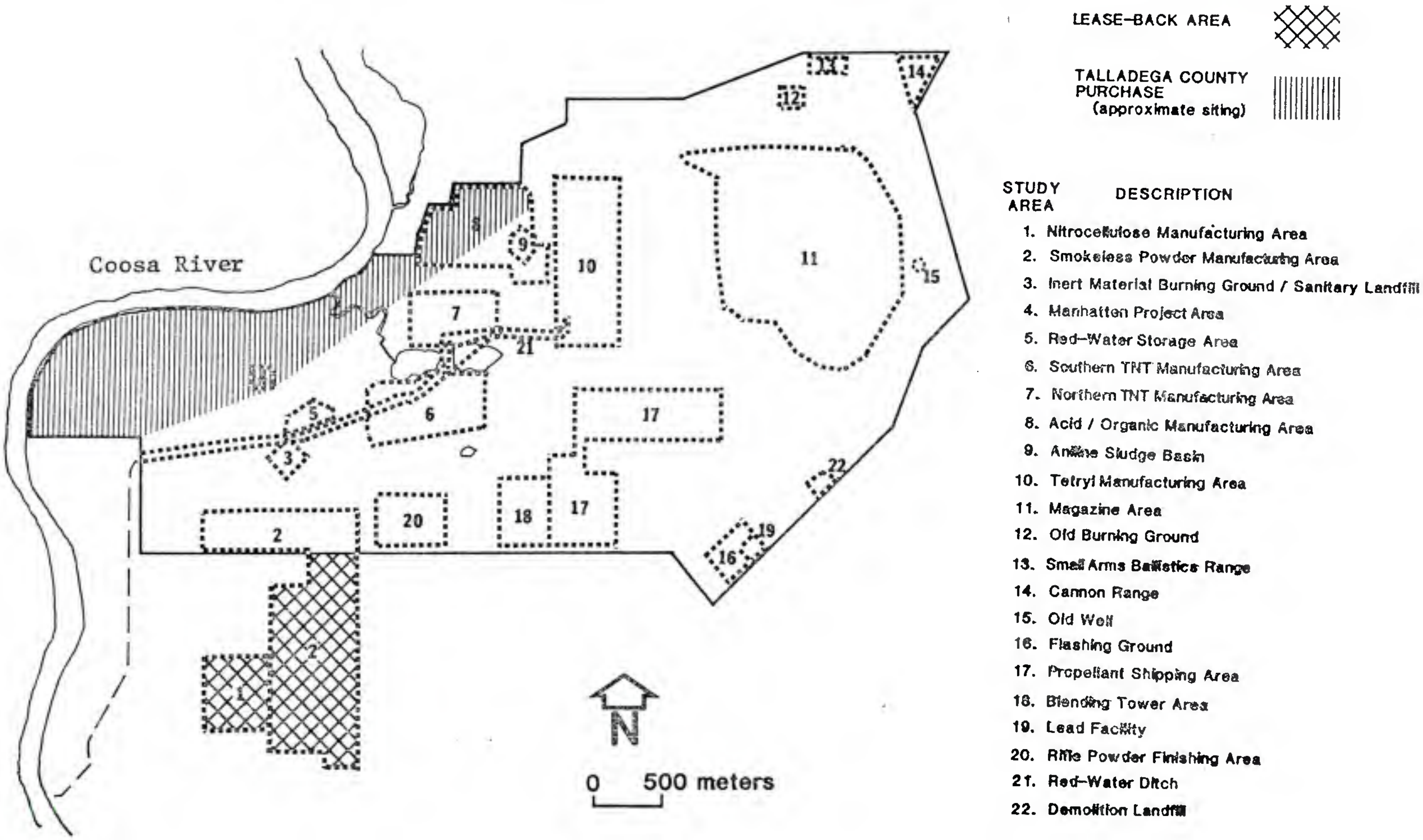

Figure 1. Location of Designated Study Areas.[7]

designations of Figure 1 will be used in the text. The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) has contracted to have soil surveys performed at these areas of the plant. Table 1 summarizes the results of such surveys as of November 1980. Based on information from USATHAMA personnel, about 94 acres are considered to contain the bulk of the contamination.[6] Contamination in the old production areas is generally scattered and highly localized. Burning grounds and landfills have intense areas of contamination. For example, areas 12, 16, 19, and 22 involve approximately 14 acres of land considered contaminated, but contain the majority of the contaminated soil. Estimated soil volume for these four areas is 69,000 m^3.[7]

Additionally, two sections of land are of particular interest to the Army:

1. The cross-hatched section in Figure 1. This land (area 1 and the southern portion of area 2) was purchased by the Kimberly-Clark Company. The land was found to be contaminated, and was leased back to the Army for clean-up operations. This section is not included in the 94 acres cited above.

2. A 300-acre region comprising areas 4 and 8, and portions of the property to the west and north of these areas. This land is being considered for sale to Talladega County as the site of a gasohol plant.[8]

KNOWN OR SUSPECTED POLLUTANTS SELECTED FOR STUDY

Based on the site surveys listed in the section on Site Background, on historical records, and on discussions with USATHAMA personnel,[5] the following substances were selected for PPLV development:

1. TNT, a high explosive.

2. DNT. The 2,4-isomer is used primarily in smokeless powder formulations. Moreover, in the manufacture of TNT, 2,4-dinitrotoluene is present as a by-product at about four times the concentration of 2,6-dinitrotoluene.[9]

3. Tetryl, a booster explosive.

4. Lead (to include inorganic salts). The salts were probably derived from burned smokeless powder mixtures and perhaps from environmental action on metallic lead.

5. TNB, primarily a product of TNT degradation in the environment.

6. Nitrocellulose, the base for all propellant formulations.

7. 1,3-Dinitrobenzene, a suspected by-product in the production of TNT. It is probably formed from the nitration of impurity benzene in the raw material toluene.

8. Diphenylamine, an ingredient in smokeless powders.

9. Aniline, the starting material for N,N-dimethylaniline, an intermediate in the production of tetryl.

TABLE 1. ALABAMA ARMY AMMUNITION PLANT SOIL CONTAMINANTS: SUMMARY OF SURVEYS[5,6,7]

Contaminant	Area	Observations
2,4,6-Trinitrotoluene (TNT)	3	a
	6	b
	7	b
	12	<37-694 ppb[c]
	16	<37-2350 ppb
2,4-Dinitrotoluene and 2,6-Dinitrotoluene (DNT)	2 (lease-back)	<112-1440 ppb
	6	b
	7	b
	11	208 ppb in 1 of 18 samples
	12	<102-875 ppb
	16	<102-1845 ppb
	17	208 ppb in 1 of 28 samples
	20	<112-6095 ppb
2,4,6-Trinitrophenyl-methylnitramine (tetryl)	10	a
	16	<257-6624 ppb
	20	> 500 ppb
	22	554 ppb in 1 of 2 samples
Lead (elemental and salts)	1 (lease-back)	<10-3000 ppm
	4	300 ppm in 1 of 2 samples
	12	23-1610 ppm
	13	Metal in bullets
	16	50-2000 ppm
	19	70 PPB-1600 ppm
	22	354 and 2160 ppm in 2 samples, metallic lead visible
1,3,5-Trinitrobenzene (TNB)	2 (lease-back)	614 ppb
	6	b
	7	b
	8	b
	11	<368-2540 ppb
	16	<368-3920 ppb
Nitrocellulose	16	<42-65 ppm
	17	139 ppm
	18	56 ppm
	20	1290-1490 ppm

a. Crystalline material suspected of being this contaminant is visible in soils in this area.
b. Reported in references 5 and 6; numerical data not available.
c. 1 ppb = 1 μg/kg; 1 ppm = 1 mg/kg.

10. N,N-dimethylaniline, the immediate precursor in the production of tetryl.

11. Nitrobenzene. The source of this substance is not known, but it has been reported at Area 22.[5] The compound may have been a precursor to aniline.

OVERVIEW OF THE PPLV METHOD

The PPLV method was developed to address the land and water pollution situation that had arisen from discontinued military and civilian production activities at Rocky Mountain Arsenal, CO.[1] Several pollutants were suspected of being leached to groundwater, and the State of Colorado issued a "cease and desist" order to halt further contamination. A method was needed to provide rough estimates of acceptable groundwater and soil levels of contaminants.

The PPLV method is primarily based on the premise that human life is to be safeguarded from the adverse effects of pollutants. Where soil is the medium of concern, computations of the method are involved with:

1. Determination of an acceptable daily dose of a substance to humans,

2. Computation of the corresponding soil level that could produce such a dose for each of specified pathways through which the substance interacts with man, and

3. Computation of a soil level for the substance based on concurrent consideration of all the different pathways.

The PPLV method entails relatively uncomplicated methods. This is in recognition of the scarcity of information in the literature for other than regulated or special-concern substances such as heavy metals and pesticides. Estimated soil limits can be projected from such a scanty data base, and major areas of data deficiency can be highlighted. The method is highly assumptive, a usual consequence of simplicity in models. Where sufficient information indicates that the assumptions are not valid, more sophisticated models should be considered; these can usually be incorporated within the PPLV framework.

The first step is to determine which substances and soil-human pathways are to be considered. Substance consideration begins with a review of past land utilization, and should be augmented by on-site sampling. Logic may indicate deletion of some substances, notably volatile solvents, while environmental chemistry considerations may suggest that certain others have disappeared. A pathway is selected if there is reasonable expectation, given the local situation, that a given substance in the soil can be transmitted to man via ingestion or inhalation. Pathways that would exist in hypothetical future land use situations are also candidates for selection. The selector must temper his decisions with the realization that additional investments of time and research are incurred with additional pathway considerations. Sometimes cursory consideration of a speculative pathway will indicate that that pathway is not meaningful, compared to co-existing pathways.

The second step of the method is to identify and collect those data required for computations. The one datum common to any PPLV computation is an acceptable daily dose (D_T) to humans.

An initial determination is required to decide whether to consider a substance as a potential carcinogen (more properly "oncogen," to human beings, as it will determine the procedures and significance of D_T. A substance is considered a potential carcinogen if any of the following statements apply.

1. It is treated as such in U.S. Environmental Protectiodn Agency water quality criteria documents.[10].

2. It has been found carcinogenic in comprehensive lifetime bioassays on two rodent species.

3. It is listed as a category I or II substance in the "suggested list of carcinogens" for inclusion in 29CFR1990.[11]

It is generally accepted that non-carcinogens can be ingested or inhaled at some non-zero dose level and have no harmful long-term effect. D_T, in this case, is an estimation of that dose level. Carcinogens are generally agreed to have the theoretical potential for causing cancer at any dose level. On the strict basis of preventing harmful human effects, no carcinogenic contaminant should be retained in soil. However, the attainment of a "zero" level by land renovation could be astronomical in cost.

A more dispassionate approach is to assess a substance's dose-risk relationship for carcinogenic effects. Carcinogenic risk (R) is expressed in terms of R = probable additional risk of cancer in the lifetime of an exposed human. Alternatively, R implies one probable additional case of cancer in the lifetimes of 1/R exposed persons. Commonly used dose-risk relationships employed by the U.S. Environmental Protection Agency[10] presume that dose and risk can be assumed linearly related in a region about the zero dose.

Risk can be computed for human activities. The authors observe that risk levels of 10^{-2} to 10^{-4} are associated with voluntary actions, such as injury or death from automobile accidents. Risk levels in the range of 10^{-4} to 10^{-7} appear to be associated with involuntary mishaps, for example, injury or death from such "acts of God" as tornados, floods or bee stings. The authors perceive that public policy now developing for dealing with carcinogenic substances in the environment is based on the rationale that such substances should not pose risk levels greater than those from involuntary mishaps. This rationale amounts to a decision of expediency, which is relevant to the Army land-disposal situation. A welfare-economic decision is involved, where public funds are spent to directly benefit a few individuals. Some balance is required between the carcinogenic risk associated with substances on such land, the benefits from use of such land, and the costs of providing the land. No formal policy has evolved as to how this balance is to be determined. One factor that would be involved is the size of the population at risk. This is part of the rationale for making the computations in the section on Scenario Analysis for Land Use Intensity.

D_T estimation for a non-carcinogen involves review of the toxicological literature with the intent of finding relevant no-effect dose information. A preference literature approach based on the type of information available is recommended to best assure use of that which is most relevant. Such literature, in most to least preferable order, is in part:

1. Acceptable daily intakes (ADI) recommended by the joint WHO/FAO expert committee on food additives.

2. Drinking water standards.

3. Human ingestion water quality criteria such as those summarized in reference 10.

4. Threshold limit value (TLV) documentation for substances in workroom air.[12]

5. Published lifetime mammalian feeding studies (chronic feeding studies).

6. Published long-term (approximately 90 days for rats or mice) mammalian feeding studies.

7. Published one-dose (acute) oral toxicity studies on mammals.

Regardless of the literature used, the contents should be critically reviewed.

The mathematical relations involved in computing D_T from such information have been listed,[2] and with the exception of the D_T - TLV relation, are used herein. That relationship has been revised to the form

$$D_T = TLV \times RB' \times (5/7) / (100 \times BWA) \tag{1}$$

where D_T is in mg/body weight/day; the TLV is in mg substance/m^3 of air; RB′ is the workday breathing rate (12.1 m^3/day); (5/7) adjusts from a workweek to a calendar week, and BWA is adult body weight (70 kg).* The constant 100 is included as a safety factor to provide for sensitive humans (the young and elderly), and for the involuntary nature of such exposure. Numerically, Equation 1 is:

$$D_T = 0.0012 \times TLV \tag{2}$$

The next step involves computation of the single pathway PPLVs (SPPPLVs). The assumption at this step is that each pathway is the only pathway that transmits the substance of concern from soil to man. Each pathway is treated as a consecutive compartmental model through which the substance passes. For example, the pathway "livestock consumption" or ingestion of meat from animals fed plants grown in contaminated soil involves pollutant transfer from soil to plant and thence to animal. In the absence of refined information, each transfer is assumed to be characterized by a partition coefficient. The relations derived are of the form:

$$C_{si} = IF \times D_T / K_i \tag{3}$$

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* Unless otherwise specified, the nomenclature used in this report follows that of references 1 and 2. The data used here are from reference 1. All symbols in this report are included in the glossary.

where C_{si} is the computed SPPPLV for pathway i in mg pollutant/kg soil; IF is an "intake factor" that typically includes information about human weight and the daily rate of ingestion; and K_i is the overall partition coefficient for the pollutant between soil and the matter ingested by man. In the above example, partition coefficients K_{sp} (soil to plant) and K_{pa} (plant to animal) are involved, and $K_i = K_{sp} \times K_{pa}$.

The PPLV is computed from its component pathway's SPPPLVs. Heretofore, each pathway has been considered as the only pathway by which the substance reaches man. In fact, each pathway provides a portion of D_T; all pathways taken together provide D_T. For each pathway, the relationship between soil content and D_T can be written as

$$SPPPLV_i = C_{si} = R_i \times D_T \tag{4}$$

where, by comparison to Equation 3, $R_i = IF/K_i$. To compute PPLV from these equations, two requirements are that

$$\sum D_{Ti} = D_T \tag{5}$$

where D_{Ti} is the portion of D_T delivered by each pathway for a PPLV value of C_{sf}, and that

$$R_i \times D_{Ti} = C_{sf} \tag{6}$$

Equations 5 and 6 are analogous to direct current parallel resistance circuit equations where C_{sf} is a "potential," D_{Ti} is a "current" and R_i is a "resistance." From this analogy, the following equation results:

$$C_{sf} = D_T / \left(\sum 1/R_i \right) \tag{7}$$

Through substitution of Equation 4 to eliminate R_i in favor of C_{si}, the PPLV based on component SPPPLVs is:

$$C_{sf} = 1/ \left(\sum 1/C_{si} \right) \tag{8}$$

or

$$PPLV = 1/\left(\sum 1/SPPPLV_i \right)$$

In the treatment developed above, potential difficulties have been perceived for compounds that were mutagenic to micro-organisms (Salmonella) in the Ames battery of tests, but for which oncogenesis had not otherwise been established.* Such a manifestation of mutagenicity enhances the desirability of carrying out chronic toxicity testing in at least two mammalian species. The proposal has been made* that any D_T-value obtained for such a compound by the procedures described above (which are herewith collectively desginated "method 1") should be reduced by a factor of 100 ("method 1"), pending acquisition oe enough information to clear the compound of implied oncogenicity or to provide sufficient data to permit oncogenic criteria levels to be established by accepted procedures.

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* Comments and "subjective" proposal to use a factor of 100, by Mr. Jesse J. Barkley, Jr., Acting Environmental Program Coordinator, Environmental Protection Research Division.

LAND USE SCENARIOS AND PATHWAYS

Land use scenarios and component pathways were selected in the course of discussions between the authors and USATHAMA.[6] These selections appear in Table 2.

Several assumptions were made in deciding these:

1. Water pathways would not be addressed. This would have involved ingestion of water that had been in contact with contaminated soil. The rationale used was that well water would come from an aquifer below bedrock (see Site Background section); at the depths involved, the groundwater would not contact contaminated soil. Fish consumption was also neglected. No significant utilization of local surface water resources for that purpose was anticipated.

TABLE 2. LAND USE SCENARIOS AND PATHWAYS CONSIDERED

	Pathways				
Scenarios	Vegetable Consumption	Livestock Consumption	Dairy Consumption	Soil Ingestion	Dust Inhalation
Subsistence agriculture	X	X	X	X	
Residential housing	X			X	
Apartment housing				X	
Industrial					X
Hunting		X			
Timber harvesting					X

2. The present study would be restricted to the approximately 94 acres considered to involve the bulk of contaminants at the plant.

SCENARIO DISCUSSION

The subsistence farming scenario assumes that the 94 acres of land would be farmed in such a manner that the population could derive the bulk of its dairy, meat and vegetable requirements. The acreage taken up in houses, barns, storage silos, etc. is not subtracted from the total. Moreover, the persons involved consume meat in lieu of fish or poultry.

The residential housing scenario assumes that the 94 acres of land is subdivided for individual housing units. The families are presumed to derive the major source of their vegetable diet throughout the year from home gardens.

The apartment housing scenario treats the case where the 94 acres of land is used for more intensive human habitation than above. It is assumed that the land is not used for any food-producing activities.

The industrial use scenario involves no permanent habitation on the 94 acres of land. Industrial use is anticipated to involve considerable outdoor activity for selected workers. The major concern is with inhalable dust raised from materials-handling vehicles.

The hunting scenario involves the absence of any human activity on the 94 acres of land except for the hunting of non-domesticated animals, specifically deer. Venison would augment the meat diet of the hunter's family. During a year, a family would consume the venison of one deer.

Timber harvesting is not discussed in detail as a separate scenario. It may be considered as a very occasional activity, otherwise resembling the industrial scenario.

PATHWAY DISCUSSION

Vegetable consumption is referred to as pathway 1. This involves the use of indigenously-grown crops as the major source of vegetable diet throughout the year. This is somewhat safe-sided since not all vegetables can be preserved. The equation applicable to pathway 1 is:

$$C_{s1} = BWA \times D_T/(VC \times K_{sp}) \tag{9}$$

where C_{s1} is this SPPPLV in mg pollutant/kg dry soil; VC is the kg/day of vegetable matter ingested daily (dry weight basis);* and K_{sp} is the partition coefficient for the pollutant between soil and plant. K_{sp} has units of mg pollutant per kg dry plant weight/mg pollutant per kg dry soil.

Both livestock consumption and venison consumption are considered special cases of Pathway 2. Livestock consumption involves the use of pigs or beef cattle for the family meat supply. The animals consume crops grown on contaminated land. In terms of per-capita United States meat consumption, these animals account for over 95% of the source animal supply.[13] Relative consumption of beef to pork is slightly less than a 2:1 ratio. The either-or approach adopted will show which animal provides the worse-case situation.

In the hunting scenario, Pathway 2 is associated with the incidental consumption of venison from deer. These animals, unlike domesticated cattle, can wander over an unrestricted land area including uncontaminated land. The SPPPLV for deer is subject to adjustment for this difference.

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* This version differs somewhat from that used in references 1 and 2. Here, vegetable and meat information is used directly; previously, this information had been estimated as a fraction of overall diet.

The equation applicable to pathway 2 is:

$$C_{s2} = BWA \times D_T/(MC \times K_{sp} \times K_{pa}) \tag{10}$$

where C_{s2} is this SPPPLV in mg pollutant/kg dry soil; MC is the kg/day of meat consumed;* and K_{pa} is the partition coefficient for the pollutant between plant and meat. K_{pa} has units of mg pollutant per kg meat/mg substance per kg dry soil. Equation 10 assumes that a grazing animal does not get appreciable pollutant ingested along with soil in ingested plant material. Appendix A includes a computation of the soil contribution when $K_{sp} = 1$, and suggests that it is minor enough to be neglected.

Dairy consumption will be referred to as Pathway 3. Dairy products do include items such as butter, cheese and ice cream. Even in rural Alabama it is unlikely that a family would produce these items from milk. Thus, an assumption that all dairy products in the diet come from the milk of cows fed plants grown on contaminated soil is somewhat safe-sided. The equation applicable to this pathway is

$$C_{s3} = BWA \times D_T/(DC \times K_{sp} \times K_{pa} \times K_{ad}) \tag{11}$$

where C_{s3} is this SPPPLV in mg pollutant/kg dry soil; DC is the kg/day of ingested dairy products; and K_{ad} is the partition coefficient for a substance between animal fat and milk fat, expressed in mg pollutant per kg of milk fat/mg contaminant per kg animal fat. Organic comounds may preferably distribute to milk fat as contrasted to animal fat. K_{ad} provides for a calculation of this distribution.

Soil ingestion is referred to as Pathway 4. This pathway is restricted to young children. The most prevalent mode of soil ingestion is by incidental means in outdoor play activities. This situation will be considered here. The applicable equation is:

$$C_{s4} = BWC \times D_T/SC \tag{12}$$

where C_{s4} is this SPPPLV in mg contaminant/kg dry soil; BWC is a child body weight in kg; and SC is the kg/day of dry soil consumed.

An unusual condition, the abnormal ingestion of large amounts of non-food substances is called "pica." Pica is perhaps nutritional or psychological in cause.[14] Attention has been focused on pica owing to inner-city children's habits of eating peeling paint flakes from old buildings, which have a high lead content. The percentage of children with pica is not well-known; estimates of 6 to 50% in young children have been advanced.[15] The authors assume that nutritional or other factors that may be conducive to pica in small children will not be applicable in the scenarios considered.

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* This version differs somewhat from that used in references 1 and 2. Here, vegetable and meat information is used directly; previously, this information had been estimated as a fraction of overall diet.

Dust inhalation is referred to as Pathway 5. This involves the exposure of outdoor workers to contaminants via inhaled dust. Various occupational scenarios could be specified; the approach taken here is to model one rather dusty environmental situation. The result is a conservative-sided SPPPLV. Alternative occupations such as timber harvesting could be compared to the model and a conclusion drawn as to the applicability of the model computation (see Discussion). The equations for this pathway are more complicated than for the previous ingestive pathways, and will be developed in the section on SPPPLV Computations for Organic Substances.

SCENARIO-RELATED DATA FOR SUBSEQUENT ANALYSES

The data base for populations associated with land use scenarios and PPLV computations is rather extensive. For clarity, scenario-specific information is presented here in order of use in subsequent sections. Where information is associated with equation variables presented in the text, the symbols are also shown. All symbols used in the text appear in the glossary.

For many factors, alternative literature sources exist that could provide somewhat different values. The authors consider the values used as reasonably representative of the "real world." Ideally, factor data highly representative of a specific locality should be used. However, for the implied precision of PPLV results here, the resource expenditures to refine these data did not seem to be justified.

FACTORS FOR LAND-USE POPULATION INTENSITY COMPUTATIONS

Item	Value	Reference	Remarks
	Human Consumption Factors		
Dairy (DC)	0.756 kg/day	16	18-year old male basis
Vegetable (VC)	0.459 kg/day	16	Basis as above, includes "garden fruits" such as tomatoes and green peppers
Meat (MC)	0.290 kg/day	16	Basis as above, assumes replacement of fish and poultry in the model diet by beef or pork
	Animal Factors		
Milk production	18.44 kg/day	17	
Dairy cow grazing area	2.5 acres	18	
Beef cow grazing area	2.0 acres	19	
Life of beef cow	24 months	20	
Beef yield per animal	271 kg	21	
Pork yield per animal	63.6 kg	22	
Life of pig	6 months	22	
Corn eaten by pig	900 lb (lifetime)	22	
	Vegetable Factors		
Yield per acre	4540 kg/year	23	Assumed applicable for vegetables
Corn yield for pigs	82 bushels/acre	24	1 bushel = 55 pounds
	Population Density Factors		
Residential housing	15 people/acre	25	light residential
Housing units in apartments	6 units/acre	26	3 floor walk-up
Persons per family	3.75 - 4.0		Authors' estimate
	Others		
Deer kill at Alabama Army Ammunition Plant	202/year	3	

FACTORS USED IN SPPPLV COMPUTATIONS

Item	Value	Reference	Remarks
	Animal Fat Contents (FA)		
Fat fraction in beef	0.30	22	
Fat fraction in pork	0.45	22	
Fat fraction in venison	0.20		Authors' estimate
Fat fraction in milk	0.0391	17	
	Human Data		
Adult weight (BWA)	70 kg	10	
Work-day air volume inhaled (RB')	12.1 m^3	1	
2-yr child weight (BWC)	12 kg	27	
Adult consumption factors	See note 1		
2-yr child consumption factors			
Dairy	0.56 kg/day	16	
Meat	0.136 kg/day	16	Includes fish and poultry
Vegetables	0.125 kg/day	16	Includes "potatoes and other vegetables"
Soil ingested by 2-yr old	100 mg/day	28	See note 2
	Other Animal Data		
Live cattle weight	542 kg	17	
Live pig weight	109 kg	22	
Forage intake by cattle	16.5 kg/day	17	Dry weight basis
Soil intake by cattle	0.72 kg/day	29	See note 3
Live deer weight	83 kg		Authors' estimate, 15% of cattle weight
Venison yield	44 kg/animal		Authors' estimate, note 4
Percent of time deer occupy contaminated land	10%		Authors' estimate
	Vegetable Data		
Dry weight fraction	0.16		See note 5

1. Human consumption factors as shown in tabular data on previous page.
2. Soil consumption by 2-year old children is understandably difficult to quantify. Estimated soil or paint chip ingestion for pica are of the order of two to five or more times the level assumed here.[15,28]
3. Based on studies of pasture-fed cattle in New Zealand. Variation by a factor of least 2 may be expected as the result of variations in the amount of supplemental feed (without soil) and grazing intensity.
4. Dressed deer kills (animals already eviscerated) weigh about 66 kg in the Frederick, MD area. The authors surmise that 2/3 of this weight is ultimately consumed.
5. Based on authors' computations with representative per capita vegetable consumption values[13] and dry weights[30] of individual items.

SCENARIO ANALYSIS FOR LAND USE INTENSITY

This section provides human population figures associated with each scenario. Such figures may be of value in assessing the costs and benefits of a land renovation decision. They are intended as rough estimates. The data base is in the subsection on Factors For Land-Use Population Intensity Computations.

SUBSISTENCE AGRICULTURE

The area per person for each component of the scenario is computed.

Dairy

Daily milk production of 18.44 kg will provide for the needs of 24.4 persons. Based on 2.5 acres/cow, 0.103 acre of land is required per capita.

Vegetables

Based on a 4540 kg/year yield per acre, and an annual consumption per capita of 167.5 kg, 0.037 acres of land provides for the needs of each consumer.

Meat

Based on data in the subsection on Factors For Land-Use Population Intensity Computations and the subsection on Factors Used in SPPPLV Computations, one slaughtered beef cow will provide 1.28 persons' meat supply for 2 years. Based on 2 acres/animal, the net acreage per capita is 1.56. The actual acreage could be considerably higher, especially if a breeding herd is maintained.

The yearly meat needs of 1.20 persons can be provided by two pigs (one slaughtered each 6 months). One acre of land provides 4,510 lb of corn/year, which can feed five animals. Accordingly, on a per capita basis, 0.33 acres is required.

A larger population per acre can be accommodated with a pork-based meat supply than with a beef-based meat supply. On a per capita basis, 0.47 acres of land provides the dairy, vegetable and meat requirements. Assuming all 94 acres are so used, as many as 200 persons could be supported.

RESIDENTIAL HOUSING

An assumed 15 person/acre density would involve 1,410 persons residing on the 94 acres of concern. The vegetable needs for 15 persons requires 0.56 acres. If one considers each acre to have four homes, and the land needs for driveways and streets, most of the unused land would be involved in vegetable gardens.

APARTMENT HOUSING

Based on six units per acre, a population density of 23 persons per acre is estimated; on 94 acres, 2,160 persons could be housed.

INDUSTRIAL USE

The authors' judgment is that a maximum of 200 persons would be at risk to dust inhalation.

HUNTING

Based on recent deer kill numbers and a typical family size, about 750-800 persons could be involved.

SPPPLV COMPUTATIONS

SPECIAL CASES

Of the 11 substances chosen, data for nine are processed by typical methods. Data for the two others requires different approaches.

Nitrocellulose is a highly insoluble, fibrous material. Its toxicity has been well-studied and such studies have been reviewed by Dacre.[31] The material acts as inert dietary bulk, and any adverse responses that were seen in small laboratory animals appear related to physical blockage of their intestinal tracts. Accordingly, no D_T-based PPLV related to ingestion can be devised. On the other hand, nitrocellulose appears amenable to PPLV treatment in the industrial use scenario/inhalation pathway. Nitrocellulose is produced from cotton linters, and it appears that nitrocellulose effects would be due to its fibrous substrate. A TLV recommendation of 1 mg/m^3 for cotton dust[12] has been established, and this seems appropriate for nitrocellulose.

Lead is ubiquitous. Lead pollution has been well-studied, and certain generalizations can be made:

1. Children present a high-risk group for ingestion pathways.

2. The intake of lead from soil by plants is not highly related to the lead content of soil.

3. Lead is selectively stored in animal organs such as bone, liver and kidneys.

Accordingly, the approach taken for lead will be more in-depth than indicated by the equations in the section on Land Use Scenarios and Pathways.

Consideration must be given for a model 2-year old child as well as for the model adult considered in the typical PPLV method; different pathways may be critical for adults and children within the same scenario. Moreover, child considerations may be the more stringent in determining a PPLV. A recommended safe ingestion level for all food and drink of 600 μg Pb/day for adults appears a reasonable starting point for a model adult.[32] Estimated lead intakes from dietary sources not specifically considered must be deducted from this level. Adults ingest lead in such diet items regardless of scenario. Water and beverages (other than dairy-derived) are presumed to provide 25 μg Pb/day, based on estimates in reference 33. Other dietary components,

primarily fruits, grains, and cereal products, are assumed to provide an additional 40 µg Pb/day, based on estimates in reference 16. This leaves 535 µg Pb/day for intake from the dietary components discussed herein.

A recommended safe ingestion level of 300 µg Pb/day for 1- to 3-year old children has been suggested,[34] apparently on the basis of intakes and the corresponding lack of observed harmful effects. This level has been criticized for children at the lower ages; Mahaffey[34] has recommended 150 µg Pb/day for 6-month to 2-year old children. Paradoxically, the adult level above, when simply extrapolated on a weight basis to a 2-year old child, indicates a 103 µg Pb/day level. As a compromise, a starting lead intake of 125 µg PB/day is adopted here. Measured lead contents in water, grain, fruits, and cereal products,[16] add up to about 30 µg Pb/day intake in a model 2-year old child's diet.

The industrial use scenario presupposes exposure of a less sensitive population through the inhalation route. For occupational situations, an "action level" of 30 $\mu g/m^3$ has been established.[14] If the lead concentration in air exceeds this level, an employer must commence passive actions (monitoring, medical surveillance and employee training). Due to the rather extensive human studies of lead involved in this regulation and the technical and legal review afforded it, 30 $\mu g/m^3$ is used in calculating permissible levels for inhalation exposures.

D_T-VALUES

For TNT, an in-depth review of current toxicological studies was undertaken by Dacre.[31] The most revelant value for D_T was a no-effect level of 1.4 mg/kg/day based on a 90-day rat feeding study. The estimated D_T for TNT is therefore 1.4×10^{-3} mg/kg/day.[2] This is a "method 1" calculation (see p. 11). Owing to the observation of microbial mutagenesis in an Ames battery of tests,[34a] a "method 2" calculation was also made, giving a D_T of 1.4×10^{-5} mg/kg/day. Chronic toxicity testing is currently being pursued on TNT in three mammalian species. When this process has run its course, and the results have been evaluated, it should be possible to provide a definitive value of D_T if TNT is not oncogenic, or a criterion-dependent value if it is.

The estimated human effects of DNT, particularly 2,4-dinitrotoluene, are well documented in recently-issued water quality criteria.[10] This substance is considered a potential carcinogen. The authors consider a risk of 10^{-5} as appropriate to land use scenarios at Alabama Army Ammunition Plant; for this risk level the value of D_T computed from criteria data is 3.2×10^{-5} mg/kg/day.

Tetryl has a recommended TLV of 1.5 mg/m^3.[12] Based on Equation 2, the D_T estimate is 1.8×10^{-3} mg/kg/day.

TNB has not been intensively studied with the intent of finding no-effect level doses. The most applicable data available are from a rat feeding study by Fogleman, et al.;[35] the LD50 estimated for rats is 505 mg TNB/kg. Following the methods of Reference 2, the corresponding D_T of 5.8×10^{-3} mg/kg/day is estimated. This is a "method 1" calculation (see p. 11). Owing to the observation of microbial mutagenesis in an Ames battery of tests, a "method 2" calculation has also been included for TNB, giving a D_T of 5.8×10^{-5} mg/kg/day.

1,3-Dinitrobenzene has a recommended TLV[12] of 1 mg/m^3 although the information base is dated and of somewhat dubious reliability. Based on Equation 2, the D_T estimate is 1.2×10^{-3} mg/kg/day.

Diphenylamine reportedly[36] has a recommended ADI of 0.02 mg/kg/day. This value is used as the D_T estimate.

Aniline has a tentative recommended TLV of 10 mg/m^3.[37] Based on Equation 2, the D_T estimate is 1.2×10^{-2} mg/kg/day.

N,N-Dimethylaniline has a recommended TLV of 25 mg/m^3,[12] which appears to be founded on a tenuous data base and comparisons to aniline analogs. Through use of Equation 2, the D_T estimate is 3.0×10^{-2} mg/kg/day.

Nitrobenzene has a recommended TLV[12] of 1 ppm or 5.13 mg/m^3. Based on Equation 2, the D_T estimate is 6.2×10^{-3} mg/kg/day.

The D_T information presented above is summarized in Table 3.

TABLE 3. ESTIMATES OF ACCEPTABLE DAILY DOSES (D_T) FOR SUBSTANCES OF CONCERN AT ALABAMA ARMY AMMUNITION PLANT

Contaminant	Input Type of Information	Value	Reference	D_T mg/kg/day
TNT	90-day rat feeding study	1.4 mg/kg/day	31	1.4×10^{-3}[a] 1.4×10^{-5}[b]
DNT[c]	Water quality criteria	1.1 μg/L	10	3.2×10^{-5}
Tetryl	TLV	1.5 mg/m^3	12	1.8×10^{-3}
TNB	LD_{50}	505 mg/kg	35	5.8×10^{-3}[a] 5.8×10^{-5}[b]
1,3-Dinitrobenzene	TLV	1 mg/m^3	12	1.2×10^{-3}
Diphenylamine	Acceptable daily intake	0.02 mg/kg/day	36	2.0×10^{-2}
Aniline	TLV	10 mg/m^3	37	1.2×10^{-2}
N,N-Dimethylaniline	TLV	25 mg/m^3	12	3.0×10^{-2}
Nitrobenzene	TLV	1 ppm = (5.13 mg/m^3)	12	6.2×10^{-3}
Nitrocellulose[d]	--	--	--	1.2×10^{-3}
Lead[e]	Unofficial recommendations	--	34	8.0×10^{-3}

a. "Method 1," see p. 11.
b. "Method 2," see p. 11.
c. Extrapolation methods used for mammalian oncogens indicate that the D_T would entail an increased risk of cancer of 10^{-5}.
d. Used for dust inhalation pathway only. Based on TLV for cotton linters.
e. Based on recommended value for ingestion with adjustment made for water and food sources not considered in the present study.

PARTITION COEFFICIENTS

In general, literature that provides these constants directly is rare. The methodology for estimating such constants is still in a formative stage. For substances other than nitrocellulose (for which ingestive pathways are not applicable) and lead (for which a more rigorous approach is used), reasonable estimation methods are employed.

K_{pa} (Plant to Animal Partition Coefficient)

The argument is that animals, when fed a constant concentration of a compound in their diet over an extended time period, bioconcentrate that substance to an asymptotic level. Organic substances appear predominantly in adipose (fatty) tissue. This approach is based on an analysis of long-term rat feeding studies with various chemicals.[38] In Reference 38, a correlation of bioconcentration factor (BF) with the water solubility of a compound was proposed for use in the absence of experimental data:

$$\log BF = 1.2 - 0.56 \log SS \tag{13}$$

where BF is the mg of substance per kg of adipose tissue/mg of substance per kg of food on a dry weight basis and SS is the water solubility in µg/L.

The authors anticipate that this approach and Equation 13 is applicable to other animals. It is similar to equations derived for the bioconcentration of organic compounds in fish. The approach is preferable to the presumption of complete compound retention, and simpler to apply than a "mass balance" approach. As a singular example, the polychlorobiphenyl mixture Arochlor 1254, a very water-insoluble and highly fat-soluble substance, was fed to milk cows by Fries, et al.[17] After 60 days of constant-level feeding, milk fat levels reached apparent asymptotic levels. The experimental results permit computation of a diet-milk fat BF, which agrees well with Equation 13.* While the behavior of one substance hardly validates a model, the agreement is encouraging.

In the absence of specific available data,

$$K_{pa} = BF \times FA \tag{14}$$

where FA is the fat fraction in the animal adipose tissue, or for dairy, in milk. Pollutant solubility data and computed values of BF are presented in Table 4.

* Compare 3.45 ± 0.95 (mean ± 1 S.D. for milk fat) to 3.94, the value estimated by use of Equation 13.

TABLE 4. SOLUBILITY DATA AND BIOCONCENTRATION FACTORS FOR SUBSTANCES OF CONCERN AT ALABAMA ARMY AMMUNITION PLANT

Substance	Solubility μg/L	Ref.	BF[a]
TNT	1.23×10^5	39	2.24×10^{-2} [b]
2,4-Dinitrotoluene	2.73×10^5	39	1.43×10^{-2} [b]
Tetryl	3.5×10^4	40	4.52×10^{-2}
TNB	3.2×10^4	39	4.76×10^{-2}
1,3-Dinitrobenzene	3.7×10^5	39	1.21×10^{-2}
Diphenylamine	3.6×10^4	36	4.45×10^{-2} [c]
Aniline	3.5×10^7	41	9.45×10^{-4} [c]
N,N-Dimethylaniline	1.6×10^7	41	1.46×10^{-3}
Nitrobenzene	1.78×10^6	38	3×10^{-2}

a. Nitrobenzene's BF is a reported value,[38] others are computed frou Equation 13.

b. Based on excretion and metabolism considerations, a K_{pa} as low as 0.1 x the tabulated value may be applicable (see text).

c. Based on excretion and metabolism considerations, a K_{pa} as low as 0.5 x the tabulated value may be applicable (see text).

Four of the nine substances involved have been studied for metabolism and excretion. These studies involved a one-time dose (C-14 trace) followed by analysis for retained material after 24 hours. The proportions retained after 1 day (perhaps as metabolites) were:

1. TNT in mice, less than 10%.[42]

2. 2,4-Dinitrotoluene in rats, less than 10%.[43,44]

3. Aniline in sheep, about 50%.[41]

4. Diphenylamine in rats, about 50%.[36]

Fairly high rates of elimination, along with metabolic transformations, if applicable to cows, swine and deer, would argue for inclusion of fractional adjustments in K_{pa}. Soil bacteria ingested by ruminants (cows and deer) could enhance this process. Moreover, metabolites are generally more polar and less fat-soluble than, and should accumulate less than, their precursors. On the other hand, the extent of the removal/metabolism processes in the studies cited[38] were not established. Exclusion of fractional adjustments for elimination of metabolites would lead to lower SPPPLV estimates. Thus, their exclusion from Equation 14 is a conservative assumption.

K_{sp} (Soil to Plant Partition Coefficient)

No correlations for organic substances exist. In the absence of participation in plant metabolism, organic uptake is probably positively correlated with water solubility.[45] A few studies illustrate some extreme situations.

In one study, Fries[46] noted that the increase of DDT concentration in turnip greens, tobacco leaves and peanut forage ranged from 0.06 to 0.09 ppm for each ppm increase of DDT in soil. Water solubility of DDT is in the order of 1 to 2 μg/L. In contrast, radiolabeled para-chlorophenyl methyl sulfone, a compound with solubility in the range of 10 g/L,* was added to a sandy loam of 0.8% organic content for plant tests.[47] Plant uptakes corresponding to K_{sp} of values 40 for plant tops and 7 for roots were reported.

The substances considered here (except nitrocellulose and lead) are intermediate in solubility between DDT and para-chlorophenyl methyl sulfone. A default K_{sp} of 1.0 is used for such substances.

K_{ad} (Animal Fat to Butterfat Partition Coefficient)

K_{ad} is assumed equal to 1.44 for organic substances. The value 1.44 is based on the study by Fries, et al.,[17] and represents the ratio of Arochlor 1254 found in butterfat to its concentration in body fat. Other organic substances may have K_{ad} values closer to 1.0. Thus, the value used here is somewhat safe-sided.

SPPPLV COMPUTATIONS FOR ORGANIC SUBSTANCES

Equation 9 is applicable to Pathway 1. Data to evaluate this equation are: BWA = 70 KG; VC = 0.459 kg x 0.16 kg dry weight per kg wet weight or 0.0735 kg; and K_{sp} = 1. The resulting expression is:

$$C_{s1} = 953 \times D_T \qquad (15)$$

Equation 10 is applicable to Pathway 2. Equation 14 is incorporated into Equation 10 to provide an expression in terms of BF:

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* There are no direct solubility measurements for this obscure compound. Dr. Clarence W.R. Wade of this Laboratory has determined its octanol/water partition coefficient to be 16.2 (unpublished data). Equations relating this coefficient to solubility[48] provide estimates of the order cited above.

$$C_{s2} = BWA \times D_T/(MC \times K_{sp} \times BF \times FA) \tag{16}$$

For beef and pork, MC = 0.29 kg/day. For beef, FA = 0.3 and:

$$C_{s2} = 804 \times D_T/BF \tag{17}$$

For pork, FA = 0.45 and:

$$C_{s2} = 536 \times D_T/BF \tag{18}$$

Venison is assumed to incidentally supplement the meat diet. C_{s2} for deer is based on assumed consumption patterns (44 kg of venison from one animal per year per family), FA = 0.20, and a factor of 0.1 to account for browsing patterns that include both contaminated and non-contaminated areas. The numerical evaluation is:

$$C_{s2} = [(70 \times 365)/(0.1 \times 0.2 \times \{44/4\})] \times (D_T/BF)$$

or

$$C_{s2} = 116140 \times D_T/BF \tag{19}$$

Equation 11 (with Equation 14 substituted) is applied for Pathway 3. The new variables here are DC = 0.756 kg/day; FA = 0.0391; and K_{ad} = 1.44. The numerical result is:

$$C_{s4} = 1645 \times D_T/BF \tag{20}$$

Equation 12 is applied for Pathway 4. Here, BWC = 12 kg and SC = 100 mg/day soil or 10^{-4} kg/day soil. Thus:

$$C_{s4} = 1.2 \times 10^{+5} \times D_T \tag{21}$$

The formulation for pathway 5 is rather model-specific. The model used here includes the following features:

1. With the exception of 2,4-dinitrotoluene, the D_T values derived in section on SPPPLV Computations for Organic Substances have incorporated into them safety-factors such as was used in Equation 1. A less stringent margin of safety can be accepted for application to the working population, as the people involved are a robust component of the general population. Thus, for this pathway, $D_T' = 10 \times D_T$ is employed. For 2,4-dinitrotoluene, relaxation of D_T is not appropriate, and $D_T' = D_T$.

2. When a worker is exposed to dust, he may be exposed to as much as 10 mg soil/m^3 air concentration. This specific value is the TLV for nuisance dust in workroom air.[12] Such a concentration of dust would be considered rather extreme in out-of-doors surroundings.

3. A typical worker has a 5-day, 8-hour-per-day, week and works 225 days yearly.

4. The worker is exposed to dust only when the ground is fairly dry and only when the wind is of low enough velocity that the dust is not rapidly dispersed or when dust is blown towards the worker. These favorable dust-cloud formation factors are anticipated to jointly occur during 40% of working hours.

The daily acceptable intake for workers is D_T' x BWA. On a yearly basis, this is 365 x D_T' x BWA or 25550 x D_T'. In a working year, a worker can inhale 10 mg dust/m^3 x 225 days/year x 0.4 x 12.1 m^3 air/day or 0.0109 kg dust/year. By PPLV definition:

$$C_{s5} = 25550 \times D_T'/0.0109 = 2.34 \times 10^{+6} \times D_T' \qquad (22)$$

where C_{s5} is this pathway PPLV in mg pollutant/kg dry soil. For organic substances other than 2,4-dinitrotoluene,*

$$C_{s5} = 2.34 \times 10^{+7} \times D_T \qquad (23)$$

and for 2,4-dinitrotoluene,

$$C_{s5} = 2.34 \times 10^{+6} \times D_T \qquad (24)$$

The SPPPLVs shown in Table 5 were computed with these equations by the use of the D_T information in Table 3 and the BF estimates in Table 4. The results appear in Table 5.

PATHWAY COMPUTATIONS FOR LEAD

As discussed in the Special Cases Section, lead presents a special situation, particularly for ingestion-related pathways. The PPLV derivation from SPPPLV estimates, Equation 8, is not valid for lead, since pathways not specifically addressed in a scenario also provide lead to the diet. The problem becomes one of restricting total lead intake to less than a specific value (535 μg/day for adults and 95 μg/day for a 2-year old child). Some of these intakes are associated with contaminated soil, some are not. In this section, the pathway-based estimates for both situations are derived. The presentation of pathways is not in numerical consecutive order.

Pathway 5

The action level of 30 μg Pb/m^3 in workroom air should not cause untoward effects to most exposed workers, although there is a remote probability that clinically-detectable symptoms could occur in highly sensitive individuals.[49] For this level to be maintained by airborne dust of 10 mg soil/m^3 air concentration, a 3,000 mg Pb/kg soil content is required. Taking into consideration the pathway model assumptions of workdays and weather conditions favorable to airborne dust, a 8,530 mg Pb/kg soil concentration is computed. The authors recommend adoption of the more restrictive 3,000 mg Pb/kg soil value as this SPPPLV.

*Equation 23 can be used for nitrocellulose also. First, the assumed nitrocellulose TLV of 1 mg/m^3 is used in Equation 2.

TABLE 5. SPPPLVs (mg/kg) FOR ORGANIC SUBSTANCES OF CONCERN AT ALABAMA ARMY AMMUNITION PLANT

Substance	Pathway 1 Vegetable Consumption	Pathway 2 Consumption: Beef	Pathway 2 Consumption: Pork	Pathway 2 Consumption: Venison	Pathway 3 Dairy Consumption	Pathway 4 Soil Ingestion	Pathway 5 Dust Inhalation
TNT--"Method 1"[a]	1.33	50.2	33.5	7260	103	168	33200
"Method 2"[a]	0.0133	0.502	0.335	72.6	1.03	1.68	332
2,4-Dinitrotoluene	0.0305	1.80	1.20	260	3.68	3.84	76
Tetryl	1.72	32.0	21.3	4620	65.5	2.6	42700
TNB--"Method 1"[a]	5.53	98.0	65.3	14200	200.0	696	137000
"Method 2"[a]	0.0553	0.98	0.653	142	2.0	6.96	1370
1,3-Dinitrobenzene	1.14	79.7	53.2	11500	163.0	144	28400
Diphenylamine	19.1	361.0	241.0	52200	740.0	2400	474000
Aniline	11.4	10200.0	6810.0	1470000	20900.0	1440	284000
N,N-dimethylaniline	28.6	16500.0	11000.0	2390000	33800.0	3600	711000
Nitrobenzene	5.91	166.0	111.0	24000	340.0	744	147000
Nitrocellulose	N/A	N/A	N/A	N/A	N/A	N/A	28400

a. See p. 11 for explanation of "Method 1" and "Method 2."

Pathway 1

The complication here is illustrated by a study by Chaney, et al.[50] The lead content of soils in 50 gardens in Baltimore, MD, and foliar lead levels of collard greens grown in these gardens were determined. The foliar levels were weakly, if at all, related to soil-lead content, which ranged from 46 to 10900 mg Pb/kg. A mean foliar content of 6.3 mg Pb/kg (dry basis) was estimated.

Pathway 1 probably does not, on the basis of human effects, provide a basis for a SPPPLV. However, regardless of the geographical source of vegetables, their consumption involves ingestion of lead. Kolbye, et al.[16] reported on lead in typical diets. One complicating factor in the analysis of lead content was the sensitivity of the lead assay methods; samples often assayed as "trace" or "not detectable." Based on reasonable assumptions of what such results imply, they estimated that the vegetables in a daily diet contain 65 μg of lead. A similar analysis for 2-year old children provides a 25 μg/day estimate.

Pathway 3

Pathway 3 requires an unusual approach. Lead can be toxic to cattle; and this would place an upper limit on soil-lead content. Dairy cows graze on pastures; the lead content of the plant matter is probably insensitive to soil-lead content. Soil is consumed in the grazing process, and may provide a significant portion of the lead in dairy products.

Botts has reviewed livestock lead toxicity information.[51] He estimates that an ingestion rate of 2 mg Pb/kg animal weight/day is safe for cattle. The typical lead content for pasture plant material is not well documented, but the 6.3 mg Pb/kg value for collard greens[50] may be somewhat high-sided. Here, a 5 mg Pb/kg (dry weight) value is used. Based on a 542 kg animal, a cow may safely ingest 1,084 mg Pb/day. At representative pasture consumption (16.5 kg/day) and soil intakes (0.72 kg/day), the limiting lead content in soil on the basis of potential harm to cattle is:

$$(1084 - (5 \times 16.5))/0.72 = 1390 \text{ mg Pb/kg} \qquad (25)$$

Note that this computation is relatively insensitive to plant lead content.

A data-fitting model is proposed for relating lead-milk content to that of soil. The model is:

$$L(\text{milk}) = A1 + (A2 \times LS) \qquad (26)$$

where L(milk) is the milk content in μg Pb/kg; A1 accounts for lead intake from ingested plant matter (assumed not related to lead-soil content) and A2 accounts for proportional intake from ingested soil.

Typical milk-lead levels have been reported by Lynch, et al.[52] as 49 ppb (μg/kg) and 40 μg/L by Mitchell and Aldous.[53] The latter figure was based on a survey of 270 samples. A representative value of 45 μg/kg is assumed, and is assumed correlatable to a soil-lead content of 30 mg/kg (that occurring in background soil samples in the Alabama Army Ammunition Plant area). A proportionality factor B is first computed:

$$45\ \mu g/kg = B \times 16.5\ kg/day \times 5\ mg\ Pb/kg + B \times 0.72\ kg/day \times 30\ mg/kg \qquad (27)$$

from which B = 0.433. Equation 26 is then written as

$$L(milk) = 35 + 0.312 \times LS \qquad (28)$$

Further use of this equation (after multiplying by the daily human consumption factor) is made in Table 6.

From the typical milk-lead level above, a typical daily lead intake from dairy products for adults and 2-year old children can be computed. For adults, the intake is 0.756 kg/day x 45 μg Pb/kg milk = 34 μg Pb/day. For the 2-year old child, the intake is 0.56 kg/day x 45 μg Pb/kg milk = 25 μg Pb/day.

TABLE 6. DAILY LEAD INTAKES FROM DIET COMPONENTS OF CONCERN

Diet Component	Person	Lead Intake from Specified Diet Component, μg Pb/day: Uncontaminated Land	Lead Intake from Specified Diet Component, μg Pb/day: Contaminated Land (LS = mg Pb/kg Soil)
Vegetables	Adult	65	65
	2-year old	25	25
Beef	Adult	29	19.3 + 0.168 x LS
	2-year old	11	9.0 + 0.079 x LS
Pork	Adult	22.1	22.1
	2-year old	10.3	10.3
Venison[a]	Adult	9.3	$8.9 + 6.27 \times 10^{-3} \times LS$
	2-year old	4.2	$4.1 + 2.85 \times 10^{-3} \times LS$
Dairy	Adult	34	26.5 + 0.236 x LS
	2-year old	25	19.6 + 0.175 x LS
Soil	2-year old	3.0	0.1 x LS

a. Based on incidental use in diet, adult's nominal daily consumption of 0.033 kg/day; 2-year old, 0.015 kg/day.

Pathway 2

Estimation of the lead content in meat involves a model similar to that of Equation 26. As a complication, lead is known to accumulate preferably in bone, liver, and kidney.[51,54]

A cow will consume both pasture and soil, which causes a daily lead intake of:

$$LC = 82.5 + 0.72 \times LS \tag{29}$$

where LC is mg Pb/day intake, 82.5 is the mg Pb/day from plant material and LS is in mg Pb/kg soil. Cattle, as ruminants, have a digestive system that absorbs only 1 to 2% of ingested lead.[55] Assuming an intermediate value of 1.5% and 530 days of a 2-year lifetime on pasture,* the accumulated lead level is:

$$AL = 1.5 \times 10^{-2} \times 530 \times LC = 656 + 5.72 \times LS \tag{30}$$

where AL is the number of milligrams of lead accumulated in a lifetime.

The concentration in bone, kidney, and liver is as much as 100 times that in plasma or muscle, which, with fat, comprises beef.[50] A somewhat more conservative factor of 75 is used here. Typical weights of these three organs for cattle are available;[21,56] the total weight involved is 88 kg. Unlike organic compounds, lead salts are water-soluble, and probably do not accumulate at all in body fat; it is assumed that body fat accumulates no lead. After deductions for lead-preferring organs and fat, 318 kg of other weight remains. A mass balance on lead-containing tissues and organs is:

$$AL = 75 \times (XM) \times 88 \text{ kg} + 318 \text{ kg} \times (XM) = 6918\ (XM) \tag{31}$$

where XM is the lead content in muscle in mg/kg. The lead content in muscle as a function of lead-soil content can be computed by elimination of AL between Equations 30 and 31, namely:

$$XM = 0.0948 + 8.27 \times 10^{-4} \times LS \tag{32}$$

Since muscle comprises 70% of beef and non-lead containing fat the remainder, the lead-meat content is (with a conversion of units):

$$L(\text{Beef}) = 66.4 + 0.58 \times LS \tag{33}$$

where L(Beef) is in μg/kg.

For a non-contaminated soil with a background of perhaps 30 mg Pb/kg, the daily intake of lead from beef for adults would be 83.8 μg/kg x 0.290 kg/day or 24 μg/day; for 2-year old children, 83.8 x 0.136 = 11 μg/day.

Pork-lead content involves a somewhat simpler approach, since the assumed process of corn-feeding leads to little, if any, soil ingestion. Lead would

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* Cattle spend the first 7 months of life progressing from 100% milk dependency to a fully weaned condition.[20] They will ingest some lead from mother's milk, pasture and soil in this period. On the other hand, a 7-month calf has considerably less weight than the "typical" animal considered. A 530-day pasture life appears a reasonable compromise for these offsetting factors.

be derived from corn, which is assumed, as in Pathway 3, to have a 5 mg Pb/kg lead content. The corn consumed in a pig's lifetime is 410 kg; the corn is about 85% solids. Hence the ingested lead is about 410 kg x 5 mg/kg x 0.85 = 1742 mg. The digestive system of swine resembles that of man;[50] perhaps 10% of the ingested lead is absorbed or 174.2 mg. Lead-preferring organs in swine are assumed to involve 15% of an animal's weight or 16 kg, while the remaining non-fat weight is 0.55 (109 kg - 16 kg) or 51 kg. Analogously to Equation 31,

$$174.2 \text{ mg} = 75 \times 16 \text{ kg} \times (XM) + 51 \text{ kg} \times (XM) \tag{34}$$

or XM = 139 μg Pb/kg. Since pork is assumed 45% fat, the lead content in pork is L(pork) = 0.55 x 139 = 76.4 μg/kg. For adults, use of pork as the meat source in a diet would involve a daily lead intake of 22.1 μg/day; for the 2-year old child, 10.3 μg/day.

As a check on the realism of the beef and pork estimates, one may refer to the Kolbye, et al. study, which predicts a 20 μg Pb/day intake from meat, poultry and fish.[16] The model presented, when evaluated at a 30 mg Pb/kg soil level for a meat diet of 2:1 beef to pork predicts 26.4 μg Pb/day in the diet.

Model data on deer are not available; only a rough approximation is presented. This approximation must account for lead intake from browsing on land with background lead content as well as contaminated land. Since deer are ruminants, the treatment for cattle will be generally applicable. A deer is assumed to have 15% of the weight of a cow, and to consume plants and soil in scale similar to cattle. Thus, Equation 29 can be scaled to deer:

$$LD = 12.38 + 0.108 \times LS \tag{35}$$

where LD is the daily lead ingestion by deer. A deer is assumed to graze 90% of his diet on uncontaminated land (30 mg Pb/kg) and 10% on contaminated land. Equation 35 can be modified to account for this by considering these land categories separately:

$$LD = 0.9 \times (12.38 + 0.0108 \times 30) + 0.1 \times (12.38 \times 0.0108 \times LS) \tag{36a}$$

or

$$LD = 15.3 + 0.0108 \times LS \tag{36b}$$

Deer are assumed to absorb 1.5% of ingested lead, and to have an average 4-year lifetime. Analogously to Equation 30:

$$AL = (1.5 \times 10^{-2}) \times (4 \times 365) \times LD = 335 + 0.236 \times LS \tag{37}$$

A deer is also assumed to have 15% of its weight in lead-preferring organs or 12.5 kg, and of the remaining weight, 20% fat. Thus, analogously to Equation 31,

$$AL = 75 \times (XM) \times 12.5 \text{ kg} + 56.4 \text{ kg} \times (XM) = 994 \times (XM) \tag{38}$$

Analogously to Equation 33, L(venison) in μg Pb/kg is:

$$L(\text{venison}) = 270 + 0.190 \times LS \tag{39}$$

Pathway 4

The lead absorption in μg/day as a result of soil ingestion is simply 0.1 x LS.

PPLV COMPUTATIONS

Calculation of the PPLVs for the nine organic substances subject to the entire PPLV computational procedure involves use of the SPPPLV values from Table 5 and Equation 8. If one SPPPLV is lower than others considered by a factor of 10 or so, Equation 8 may be approximated by

$$C_{sf} = (C_{sfi})\text{ lowest } \approx \text{ minimum } C_{si} \qquad (40)$$

without excessive loss of accuracy.

The PPLV from ingested lead pathways involves a summation of lead intakes of dietary components. These have been derived in the section on Pathway Computations for Lead. For convenience, they are summarized in Table 6, with adjustments made for daily consumption rates. The summations, based on arguments in the section on Special Cases, should not exceed 535 μg Pb/day for an adult and 95 μg Pb/day for a 2-year old child.

SUBSISTENCE FARMING SCENARIO

An examination of Table 5 shows that vegetable ingestion leads to the lowest SPPPLVs, and that the value associated with this pathway for a given soil contaminant is less than one-tenth of any others. Thus, the vegetable pathway results of Table 5 would be recommended as PPLV values for this scenario.

An examination of Table 6 indicates that the beef-based diet would lead to lower PPLV-estimates than a pork-based diet. Hence, the beef-based diet will be used for subsequent computations. For adults, the lead PPLV is the soil-lead concentration which will, based on vegetable, dairy, and meat consumption, provide 535 μg Pb/day. Mathematically, this is:

$$535 = 110.8 + 0.404 \times LS \qquad (41)$$

whereupon, LS = 1050 mg Pb/kg soil.

For children, the analog to Equation 41 must include provision for soil ingestion. Hence:

$$95 = 53.6 + 0.354 \times LS \qquad (42)$$

From which LS = 117 mg Pb/kg soil. Thus, the PPLV for lead is child-determined for this scenario, and would be estimated at 117 mg Pb/kg soil.

RESIDENTIAL HOUSING SCENARIO

An examination of Table 5 shows again that vegetable ingestion is PPLV-determining, and that the vegetable results can be directly used for recommended PPLV value for the nine organic compounds.

An examination of Table 6 shows that child considerations will determine the most restrictive PPLV, and the beef-meat diet is the most restrictive option of alternatives in Pathway 2. The mathematical relation for LS is:

$$95 = 61.22 + 0.1 \times LS \tag{43}$$

or LS = 338 mg Pb/day.

APARTMENT HOUSING SCENARIO

In this scenario, only pathway 4 is involved. The values for this pathway in Table 5 can be used directly for PPLV recommendations.

The lead PPLV for this scenario is the same as computed in the previous section, as both scenarios are based on diets insensitive to lead-soil content.

INDUSTRIAL SCENARIO

Only inhalation of dust (Pathway 5) is of concern here. The values in Table 5 for this pathway would be recommended for the organic compounds. A value of 3,000 mg Pb/kg soil was developed in the section on Pathway Computations for Lead.

HUNTING SCENARIO

Only the ingestion of venison (Pathway 2 variant) is of concern here. The values for this case in Table 5 would be recommended for the organic substances.

The lead PPLV is again child-determined, and the applicable equation involves non-contaminated land sources of vegetables, beef, dairy products, the incidental ingestion of background-level leaded soil, along with the consumption of venison. The mathematical relation is:

$$95 = 25 + 11.37 + 24.85 + 3.0 + 4.1 + 2.85 \times 10^{-3} \times LS \tag{44}$$

or

$$LS = 9360 \text{ mg Pb/kg soil.}$$

DISCUSSION

For convenience, the PPLV estimates for the various scenarios are consolidated in Table 7. The SPPPLV computations show that Pathway 1 (vegetable consumption), when a relevant pathway, should be PPLV-determining. In particular, 2,4-dinitrotoluene contamination is expected to present the most serious problem, although other organic substances have been detected in soils

at Alabama Army Ammunition Plant at levels exceeding PPLV estimates. The 2,4-dinitrotoluene results are lowest, primarily because of the low D_T value assigned by reason of the criteria of carcinogenic effect. Nitrocellulose has a PPLV only for the industrial use scenario. The 28,000 mg/kg estimate (2.8% of soil) is well in excess of any known contamination at the plant.

The rather high PPLVs calculated for some pathways (10,000 mg/kg = 1% soil content by weight) would suggest that these pathways are relatively inefficient methods of challenging a human with these substances. For venison ingestion, the high values reflect the two assumptions of low nominal daily intake and of unrestricted browsing habits.

The high PPLV values in the industrial scenario could suggest consideration of direct vapor inhalation as an alternative pathway. For example, aniline has a 1 mm Hg vapor pressure at 35 ^{o}C.[57] Conceivably, pure aniline could create a saturated air mass with an aniline content of 4,800 mg/m^3, far in excess of a TLV. It is doubtful whether outdoor conditions, except in most unusual circumstances, could be conducive to maintaining this high an aniline concentration in a significant air volume. Given the 35 years from the last introduction of aniline to soil, the bulk of such vapor-generated material would have dissipated. Finally, at low concentrations, the compound would be absorbed in soil organic matter, and would exhibit a lower vapor pressure than that expected of pure compound.

From organic compound considerations, the hunting and industrial use scenarios would require little, if any, restoration efforts. A comparison of lead PPLV values to numerical lead levels determined by surveys (see Table 1) indicates a similar state of affairs. However, prudent efforts should be made to remove metallic lead deposits (reported in areas 13 and 22). Environmental action on elemental lead would cause the formation of salts that are the major lead-bearing substances of concern in SPPPLV computations.

One specific land-use scenario that was of interest to USATHAMA was timber harvesting. Timber harvesting involves intense, but short-lived activity in a given area. Moreover, decades may pass before a harvested area has trees again capable of harvesting. The scenario presented appears a reasonable representation of timber harvesting when it occurs. Given the transitory nature of the operation in a given area, PPLV estimates less restrictive than any of those presented in Table 7 would apply, and probably would indicate no need for major land renovation efforts.

The authors would expect any land renovation efforts to entail physical removal of contaminated soil and its replacement with non-contaminated soil. The requirement for removing suspected contaminated soil of 69000 m^3 volume (see section on Site Background) is not an insurmountable task; this is the equivalent of excavating an acre plot of land to a 56-foot depth. Two general strategies could be considered: to remove "hot-spots" with extreme contamination if indeed the contamination pattern indicated this was the situation; or to "remove it all" if the cost of detecting "hot-spots" should be excessive or if the land is uncontrolled as to further use. The authors do not have sufficient information available to suggest a specific approach.

TABLE 7. PPLVs (mg/kg) FOR SOIL ACCORDING TO SELECTED LAND USE SCENARIOS AT ALABAMA ARMY AMMUNITION PLANT

Substance	Subsistance Farming	Residential Housing	Apartment Housing	Industrial	Hunting
TNT--"Method 1"[a]	1.3[b]	1.3[b]	168	33200	7260
"Method 2"[a]	0.013	0.013	1.68	332	72.6
2,4-Dinitrotoluene	0.03[c]	0.03[c]	3.6[c]	76	260
Tetryl	1.7[d]	1.7[d]	216	42700	4620
TNB--"Method 1"[a]	5.5	5.5	696	137000	14200
"Method 2"[a]	0.055	0.055	6.96	1370	142
1,3-Dinitrobenzene	1.1	1.1	144	28400	11500
Diphenylamine	19	19	2400	474000	52200
Aniline	11	11	1440	284000	1470000[e]
N,N-Dimethylaniline	29	29	3600	711000	2390000[e]
Nitrobenzene	5.9	5.9	744	147000	24000
Nitrocellulose	N/A	N/A	N/A	28400	N/A
Lead	117[f]	338[f]	338[f]	3000	9360

a. See p. 11 for explanation of "Method 1" and "Method 2."
b. PPLV exceeded by some Area 16 samples (see Table 1).
c. PPLV exceeded in one or more areas (see Table 1).
d. PPLV exceeded in Area 16 (see Table 1).
e. The physical significance of such high values is discussed in the text.
f. PPLV exceeded in several areas (see Table 1).

A decision to allow apartment residential use of land would involve, for the most part, considerations based on lead levels, although area 20 has 2,4-dinitrotoluene contents that exceed this scenario's PPLV. In this case, one may wish to reconsider assumptions made in arriving at Pathway 4 SPPPLVs, particularly whether "pica" consumption is to be neglected. This would be most important in a "hot spot" removal strategy, and relatively unimportant in a "remove it all" strategy.

The situation is more straightforward for the subsistence farming and residential housing scenarios. Here, vegetable consumption is the dominant pathway. It appears that a "remove it all" approach would be needed for either scenario.

RECOMMENDATIONS

The reader is advised to reread the Report Organization and Caveats Section of the Introduction. While the authors have tried to apply reasonable approaches to the determination of PPLVs, most of them rest on assumptions that cannot be readily validated. The PPLVs presented in Table 7 are scenario-specific and based on the assumptions presented concerning scenarios and their component pathways. Should different scenarios arise, they would have to be then addressed. For example, if horse-raising were a scenario, it would be prudent to consider the toxicity of the contaminants to horses, especially lead. If pica in children were to be safeguarded against, a soil ingestion value representative of this consumption would be introduced into the computational framework.

The treatment of partition coefficients is highly rudimentary, particularly that of K_{sp}, i.e., uptake of contaminants by plants. Establishment of such factors from meaningful correlations with the physicochemical properties of pollutants would be of considerable help in properly defining the potential for exposure.

As a stop-gap, an actual test of pasture and vegetable content in highly contaminated areas of the Alabama Army Ammunition Plant would be useful in validating the computations. Of most interest are areas contaminated with 2,4-dinitrotoluene, tetryl, TNT and TNB. Should plant data indicate far less uptake than that assumed by $K_{sp} = 1$, the PPLV values corresponding to vegetable consumption would be less restrictive. Moreover, as shown in Appendix A, this assumption directly affects the importance of soil ingestion as a source of organic pollutant intake for livestock and dairy animals. The equations concerning lead intake (Equations 28, 33, and 39) are sensitive to the assumed lead content in vegetable or forage crop matter. If these contents were lower than the 5 mg/kg value used herein, the resulting PPLVs for lead for the subsistence farming and the residential housing scenarios could be adjusted.

The nitrocellulose level in soil appears to require restriction only in the industrial scenario, and that at a 28,000 mg/kg level. Other considerations may be involved should other scenarios be actively pursued, such as the potential for ignition at a 2.8% soil content. This could easily be ascertained.

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GLOSSARY OF ABBREVIATIONS AND SYMBOLS

<u>Acronyms</u>

ADI	Acceptable Daily Intake
DNT	Dinitrotoluene
PPLV	Preliminary Pollution Limit Value
SPPPLV	Single-pathway PPLV
TLV	Threshold Limit Value
TNB	1,3,5-Trinitrobenzene
TNT	2,4,6-Trinitrotoluene
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency

<u>Symbols</u> (Equation where first definition cited)

A1 (26)	Term to account for lead-content in milk associated with animal consumption of plant matter, μg Pb/kg milk
A2 (26)	Term to account for proportionate lead-content in milk as a functioning soil-lead content, μg Pb/kg milk per per mg Pb/kg dry soil.
AL (30)	Lifetime lead accumulation, mg Pb
B (27)	Proportionality constant to determine A1 and A2 from background lead-milk and lead-soil data, μg Pb/kg milk per mg Pb/day ingested
BF (13)	Bioaccumulation factor of a substance, mg/kg adipose tissue per mg/kg dry plant weight
BWA (1)	Adult body weight, kg
BWC (12)	Child body weight, kg
C_{sf} (6)	PPLV, mg pollutant/kg dry soil
C_{si} (3)	Single-pathway PPLV for numbered pathway "i", mg substance/kg dry soil
D_T (1)	Acceptable daily dose for humnans, mg substance/kg body weight/day
D_{Ti} (5)	Portion of acceptable daily dose transmitted via pathway "i"
D_T' (22)	Acceptable daily dose to workers for dust inhalation pathway
DC (11)	Dairy products consumption per capita, kg/day
FA (14)	Fraction fat in adipose tissue
IF (3)	Pollutant intake factor for a specific pathway

K_i (3)	Partition coefficient for pollutant between soil and matter ingested by man
K_{ad} (11)	Partition coefficient for a pollutant between animal fat and animal milk-fat, mg/kg milk per mg/kg animal fat
K_{pa} (10)	Partition coefficient for a pollutant between plant (forage) material and meat, mg/kg meat per mg/kg dry plant weight
K_{sp} (9)	Partition coefficient for a pollutant between soil and plant material, mg/kg dry plant weight per mg/kg dry soil
L(item) (26)	Lead content in consumed item μg/kg
LC (29)	Cattle intake of lead, mg/day
LD (35)	Deer intake of lead, mg/day
LS (26)	Lead content in animal or child-ingested soil, mg/kg dry soils
MC (10)	Meat consumption per capita, kg/day
OC (A-1)	Organic substance uptake by cattle, mg/day
PO (A-1)	Plant organic substance content, mg/kg dry plant weight
R (*)	Risk
R_i (4)	Proportionality factor to relate C_{si} to D_T
RB′ (1)	Adult workday air volume inhaled, m^3
SO (A-1)	Soil organic substance content, mg/kg dry soil
SS (13)	Solubility of organic substance in water, μg/L
VC (9)	Vegetable consumption per capita, kg dry plant weight/day
XM (31)	Lead content in muscle, μg/kg

* Page 6.

APPENDIX A

SOIL INGESTION BY CATTLE: ORGANIC SUBSTANCES

The ingested organic substance/day is given by

$$OC = (16.5 \text{ kg/day}) \times PO + (0.72 \text{ kg/day}) \times SO \qquad (A-1)$$

where OC = organic uptake/day, PO and SO are the organic content in plant and soil, respectively. With the assumption that $K_{sp} = 1$, Equation A-1 becomes

$$OC = 16.5 \times SO + 0.72 \times SO \qquad (A-2)$$

For cattle, the plant-derived intake of organic is 16.5/0.72 or 23 times that from soil. Thus, in PPLV computations where Pathway 1 or 2 are the critical pathways, neglecting soil leads to a maximum overestimate of the PPLV by 4.3%. When these pathways have little importance, the overall effect is less.

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